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Examination of shallow and deep convection processes

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Thesis of PhD dissertation

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Convection

Atmospheric convection has a great significance in all scales of meteorology. The process is an energy transfer which is realized in a vertical mass movement. As a result, the transfer and mixing of the properties of the atmosphere were been in a turbulent manner. The process is most commonly caused by a buoyancy which is caused by the density change (free convection), but may also be due to other mechanical forces (forced convection). There are two types of convection: shallow and deep convection.

Object and aims of the research

In the doctoral dissertation, two novel and unique theories are presented, one for shallow and one for deep convection. The purpose of shallow convection research is to create an area-averaged planetary boundary layer height (PBLH) *diurnal course form-classification* was used to characterize macrosynoptic weather conditions in an objective, numerical way. In the case of deep convection research, the characterization of the most striking lightning cells in the thunderstorms was dependent on the amount and quality of air available for each thunderstorm. The theory has been named the *air mass catchment theory*. In addition, a comprehensive three-year thunderstorm and lightning statistical analysis is included in the dissertation.

Data and tools

For the shallow convection research, the PBLH values were simulated with WRF (**W**eather **R**esearch and **F**orecasting). The horizontal resolution of the model runs were 5×5 km, the number of vertical levels were 44 (with levels more numerous closer to the surface), and the PBLH parameterization was calculated by the Yonsei University Schema (Hong et al., 2006) by WRF. The entire Carpathian Basin was included in the modeling range. The model data was generated for the 2012, 2013 and 2014 summer days, with 15-minutes outputs. The processing was done by the algorithm made during the research, which was written in C programming language. The comparison of the results of PBLH diurnal courses forms with the large-scale situations, was validated by comparing to the Péczely's macrosyncoptic codes (Péczely, 1957). The Péczely-situations was available from the work of Károssy (2018).

In the case of deep convection, using the RADAR composite and LINET lightning localization data of the National Meteorological Service (OMSZ), research was conducted on a purely measurement basis. RADAR data was 5 minutes timestep and 1×1 km spatial, lightning data was available with 1 μs timestep and millisecond spatial resolution. The period of investigation was 2012, 2013 and 2014. The data processing was done by using the C programs specifically designed for the task. Thunderstorm cells were identified and tracked using a TITAN-based, custom-developed system called *radarTrack*. The *radarTrack* is a simplified version of the algorithm that is operational in the OMSZ's nowcasting system (Horváth & Nagy, 2015; Horváth et al., 2012), but because of the finer timestep and the lightning associated with the cells, the two methods differ significantly.

In both research sections data management was created by *bash*, statistics by *awk* and figures by *gnuplot* scripts.

PBLH diurnal courses form classification algorithm

The motivation of a shallow convection research was to get a detailed insight into the diurnal courses of the planetary boundary layer height. During the research, two plain regions were designated in the PBLH data field calculated with the WRF model, which were referred to as *Alpokalja* and *Pannon-alföld* during the work. In addition, the PBLH diurnal course was divided into the following sections:

- the *night phase*, which lasts from the previous day sunset until sunrise,
- the *recovery phase*, from sunrise to the stagnation of diurnal course,
- the *plateau*, during which the diurnal course stagnates (does not change significantly),
- and the *collapse phase*, which leads the plateau to the night phase.

The algorithm that classifies the shape of diurnal courses performs the following steps for both regions:

1. <u>Data Preparation:</u> The algorithm reads the model data of the given day and calculates the regional average for each region for each time step, thus producing the PBLH diurnal courses. Additionally, it calculates the maximum and average duirnal course value. The algorithm proceeds to step 2.

2. Local maximum search: If a duirnal course element is satisfied that it is considered a maximum within a given interval and does not match the maximum of the diurnal course, then the form is considered as *two-peak* by the algorithm. In this case, it specifies the subcategory based on the differences between the two maximums and then proceeds to step 6. In all other cases, proceed to step 3.

3. Determining the recovery phase: If a 45-meter increase is observed over at least 8 timesteps (2 hours) in a diurnal course, then the algorithm proceeds to step 4. If this is not the case, go to step 5.

4. Plateau definition: If an oscillation is observed during at least 8 timesteps (2 hours), the algorithm considers the form a *trapeze* and determines the subcategory based on the length of the plateau. In this case, the algorithm goes to step 6, in all other cases, proceeds to step 5.

5. *Triangle* or *flat* form: The algorithm looks at the "length" of the collapse phase, similar to step 3, but in this case with -45-meter. If either the length of the recovery phases or the collapse phases, or both conditions are fulfilled, the algorithm considers the form a *triangle*, the subcategory is depending which conditions were fulfilled. If none of the conditions are the conditions which were fulfilled then the form is considered a *flat*. The last step being step 6.

6. Determine the characteristic height: The algorithm determines the most representative height of the form. This can be done in two ways, either on the basis of the duirnal course maximum or the average. Algorithm always sets the characteristic height to the higher subcategory.

A number of additional constants and minor conditions are included in the algorithm's conditionalities, which are not mentioned here, but they ensure the optimal functioning of the algorithm. By changing the constants, the process can also be adapted to specific tasks or to examine specific forms.

The algorithm is using *gnuplot* script to create figures of the diurnal courses. In the title bar of the figure is the form defined for the diurnal course in a three (for *flat* in two) characters code.

Characterization of the diurnal course forms

After the classification of the PBLH diurnal courses came the characterization of the forms and the description of the associated large-scale weather conditions. It is mentioned, how many percent of the 276 days of research period has occurred.

***Trapeze* form:** It consists of a steeply rising recovery phase, a plateau and a steeply descending collapsing phase. The diurnal course is typically high. The shape is formed in an anticyclonic weather. This form is the ideal shape of the diurnal course, so if there are no external effects, the diurnal course will take the form of *trapeze*. In the Alpokalja region 66.7% and in the Pannon-alföld region 80.1% of the cases, this is the form that has occured.

***Triangle* form:** It consists of a steeply rising recovery phase and/or a descending collapsing phase, without a plateau. The height of the diurnal course varies, it is often high. The shape is typically formed in the weather of a fast moving (cold) front. The "inclination" of the *triangle* form refers to the passage of the front. In the Alpokalja region 22.4% and in the Pannon-alföld region 13.8% of the cases, this is the form that has occured.

***Flat* form:** There is no steeply rising recovery phase or descending collapsing phase, so it has plateau neither. The diurnal course is typically low. The shape is formed after front or in wet weather conditions. In the Alpokalja region 7.6% and in the Pannon-alföld region 5.8% of the cases, this is the form that has occured.

***Two-peak* form:** It mostly resembles a *trapeze* in which a definite local minimum space can be observed at the plateau phase of the diurnal course. As a result, the diurnal course takes the shape that resembles the letter "M". The diurnal course is usually high. The form is caused by a fast-moving, powerful local or mesoscale effect. In the Alpokalja region 4.3% of the cases and only in one case of the Pannon-alföld region this form has occurred.

Comparison of results with Péczely-codes

The validation of the weather conditions associated with the forms was made on the basis of Péczely's macrosynoptic situations. Péczely (1957) distinguished six cyclonic and seven anticyclonic situation types, based on the position of low and high pressure centers with the focal point as Hungary.

In the comparison, the case number of Péczely cases in each form was shown. In addition for each form, those Péczely codes are listed, which are expected to result in the formation of the given form. Thus, based on how many percentages of the expectations have been fullfilled, the weather situation associated with the forms can be measured.

***Trapeze* form:** In the case of the Alpokalja region 86%, in the case of the Pannon-Alföld region 84% of the requirements were fulfilled. Thus, anticyclonic weather can be associated with the form.

***Triangle* form:** In the case of the Alpokalja region 80%, in the case of the Pannon-Alföld region 82% of the requirements were fulfilled. So there is a frontal weather situation for the form.

***Flat* form:** In the case of the Alpokalja region 81%, in the case of the Pannon-Alföld region 100% of the requirements were fulfilled. So the shape can be associated with behind front or wet weather situation.

***Two-peak* form:** The expectations were only fulfilled in 68%. But this can easily be explained by the fact that it is an essentially rare form and the Péczely codes describe a macrosynoptic situation while the *two-peaks* may be associated with mezosynaptic weather. Based on the detailed analysis of the results, the local weather condition associated with the form can be considered as correct.

Overall, the results demonstrated that the four shape of the area-averaged planetary boundary layer height diurnal course has associated with specific weather conditions. The *trapeze* form can be linked with anticiclonal, the *triangle* with frontal, the *flat* form with wet weather sitiuations and the *two-peak* with mezoscale conditions. Thus, the classification process can be used to numerically and objectively categorize summer weather situations as well as assist in quick monitoring of model runs.

The diurnal course classification algorithm was basically designed for shallow convection researches, but it provided a broader interpretation during the work. Therefore, forms and weather types were the subject of research, where the role of deep convection is dominant. Although the humane lobe is directly affected by shallow convection, still dangerous weather conditions are usually associated with deep convection. The most extreme deep convection process is lightning and thunderstorm activity.

radarTrack

Thunderstorms were mapped using a revised version of TITAN-based (Dixon & Wiener, 1993) cell identification and tracking algorithm which is used in the nowcasting system of the OMSZ. The method is based on counting the number of adjacent pixels above a certain radar reflectivity threshold value. An ellipse is constructed over areas where at least 8 pixels exceed 45 dBZ. The identification is carried in each time step and lightnings are assigned to the cell. The tracking possesses more steps: the algorithm checks every cell in a range, and if in the next timestep a cell with a very similar size and radar reflectivity is there, the algorithm connects them. Subsequently, the algorithm produces the statistical data of the thundercells for the whole test period and for each year.

Conclusions from the thundercell and lightning statistics

During the analyzes, the problem is that short-lived thunderstorms do not provide a sufficiently representative picture of thunderstorms and distort the results due to their large number. Therefore, *radarTrack* produces filtered and unfiltered storm statistics based on whether the cells have a lifetime greater than the 15 minutes (3 timesteps) minimum. After the evaluations, the following statements can be made:

- An average thunderstorm has a lifetime of 40 minutes, an area of 40 km^2, a diameter of 7 km, a speed of 8.6 $\frac{m}{s}$, and its course is north-northwestern. During its life, it generates 2 MegaA current with 200 lightning strikes and 22% of them are cloud-to-ground type.

- In the absence of filtering, the average life of cells is halved and their size is two-thirds compared to the filtered version, while their speed is reduced to 7.2 $\frac{m}{s}$. In addition, lightning power is halved, but the ratio of lightning strike is not significantly altered.

- So, short-lived cells should be filtered out of the test database, as their short lifetime, small size, and low lightning amount are only noise in the dataset.
- The concept of *specific current* was introduced, which seemed to be a promising parameter to select the most electrically active thunderstorms, but it did not return the invested hopes. Its very high standard deviation makes it unreliable.
- The LINET overestimates the ratio of the cloud-to-ground lightning in the vicinity of the measuring stations, but this error does not affect the total lightning amount.
- It is worth to determine the most electrically active thunderstorms on the basis of which cells at each timesteps have achieved a strike maximum.

Air mass catchment

The hypothesis was the following: from an atmospheric electrical point of view, those thunderstorms will be the most active, which are absorbing warm and wet air masses in their lifetime. The amount and quality of the air that can absorb by a thunderstorm depends on the available air mass. To characterize this, the concept of *air mass catchment* (AMC) has been introduced. As a result, the most lightening activity belongs to cells whose AMC has warm and wet air masses. To demonstrate the theory, a complex algorithm has been developed that can estimate the amount and quality of the AMC of the thunderstorms (Mona et al., 2016c). The procedure follows the following principles:

- During the movement of the thunderstorms the air masses are absorbed from the area in front of them, so that the cell's AMC can be approached in a given timestep with a circular sector toward the cell's direction.
- The sector radius is proportional to cell air intake velocity. In the absence of the parameter, the radius can be replaced by the distance of R between the cell positions.
- The Φ central angle of sector can be considered as a 90° approximation.
- After the passage of a cell, 3 hours need to pass away so the atmosphere can again contain the air masses for convection (Horváth et al., 2006). This time can be called the τ renewal time of the AMC. So, a cell's AMC contains air mass,

which is good for the convection, when another cell has not passed through in τ renewal time.

Practical implementation

In practice, the cells will have a large and good AMC, if no other cell has passed through in there AMC (with R radius and Φ central angle) in the τ period. That is, the cell must be *leading* in the cells' relative motion system. The AMC theory is considered to be well-grounded if the thunderstorms that reach the maximum lightning per timestep are considered to be the leading ones.

Conclusions from the results

The description of the algorithm described optimal settings, but sensitivity tests have also been made, which have highlighted the limitations of the procedure. The algorithm has been demonstrated through case studies. Based on the results of the thunderstorms of the three-year investigation period, the following conclusions can be made:

- The algorithm works steadily, taking into account the setpoint limits.
- With 500 possible combinations of the AMC parameters, the efficiency of the model is 82%.
- In the case of optimal settings, it is true in 86.2% that the most electrical thunderstorms have "large and good" AMC.

Theses

1. The area-averaged planetary boundary layer height diurnal course can be classified into four forms, which are suitable for classifying macrosynoptic weather situations in the summer (Mona et al., 2016a,b).

2. Thunderstorms with large number of lightning consumed a lot of air mass, which is conducive for convection (Mona et al., 2016c).

Publications related to the dissertation topic

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